Mansoura Engineering Journal

Volume 48 | Issue 5 Article 7

August 2023

Integrated Water Quality Assessment in Damietta Branch Intakes at Dakahlia Governorate, Egypt

M. ElBagoury
Civil engineer, Ministry of water resources and irrigation, Egypt, bago@f-eng.tanta.edu.eg

H. Omara
Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Tanta university, 31527, Tanta, Egypt, Hewida@f-eng.tanta.edu.eg

Bakenaz A. Zeidan
Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Tanta University, 31527, Tanta, Egypt, b.zeidan@f-eng.tanta.edu.eg

Recommended Citation

ElBagoury, M.; Omara, H.; and Zeidan, Bakenaz A. (2023) "Integrated Water Quality Assessment in Damietta Branch Intakes at Dakahlia Governorate, Egypt," *Mansoura Engineering Journal*: Vol. 48 : Iss. 5 , Article 7.
Available at: https://doi.org/10.58491/2735-4202.3066

ORIGINAL STUDY

Integrated Water Quality Assessment in Damietta Branch Intakes at Dakahlia Governorate, Egypt

Mohamed ElBagoury [a,*], Hewida Omara [b], Bakenaz A. Zeidan [b]

[a] Ministry of Water Resources and Irrigation, Egypt
[b] Irrigation and Hydraulics Department, Faculty of Engineering, Tanta University, 31527, Tanta, Egypt

Abstract

The water quality of the Damietta branch evaluated and assessed using the water quality index (WQI), including twenty-one physical, chemical, and biological parameters (Temperature, Turbidity, Chlorine, Electrical Conductivity, Total Dissolved Solids, pH, Chloride, Total Alkalinity, Total Hardness, Dissolved Oxygen, Chemical Oxygen Demand, Biological Oxygen Demand, Nitrogen, Sulfate, Calcium, Total phosphorus, Sodium, Potassium, Nitrate, Magnesium, and Total Coliform) measured at eleven different drinking water intake stations in Dakahlia governorate along the Damietta branch of the Nile river for four successive years from 2018 to 2021. The scale for evaluating the water quality of the Damietta branch of the Nile River is created using the tolerance limits of Egyptian law 'regarding the protection of the Nile River and waterways from pollution', Law No. 48/1982, and its regulations No. 92/2013. The water quality index approaches: Weighted Arithmetic (WA-WQI) and the Canadian Council of Ministries of the Environment (CCME-WQI) are used to find WQI in Dakahlia Governorate along the stretch of the Branch. The Damietta branch of the Nile River indicates good and excellent suitability for surface water use according to the tolerance and permissible limits of Egyptian law and regulations.

Keywords: Canadian Council of Ministries of the Environment-water quality index, Damietta branch, Statistical analysis, Water quality assessment, Weighted arithmetic-water quality index

1. Introduction

It's important to protect and manage the Nile River in order to develop natural resources sustainably since the Nile River in Egypt is the primary and most important source of freshwater. Egypt is one of the countries in the world that suffers most from water scarcity, and it depends 97% on the Nile River for its water needs. Egypt's share of the surface water of the Nile, on which it depends, is very limited and estimated per year at 55.5 billion cubic meters (MWRI, 2010). This gap is bridged through water reuse, and each year, imports of agricultural crops total about 34 billion cubic meters (MWRI, 2010). The Ministry of Water Resources and Irrigation works to improve the quality of water because it reuses it more than once, which is reflected in the health of citizens. The country faces many challenges, such as climate change, the Ethiopian Dam construction, population increase, limited freshwater supplies, and increased water demand, that have an impact on the quality and quantity of the Nile (EEAA, 2008).

Around the world, massive amounts of waste from Industrial, agricultural, and domestic activities are released into rivers, which is a serious environmental problem (Badr et al., 2013a; Badr et al., 2013b). The Nile River is regarded in Egypt as the major freshwater source. The household, agricultural, industrial, and tourism activities along both banks of the Nile in numerous countries upstream and downstream have an effect on the river's water quality.

2. State of the art

One of Egypt's national objectives for achieving sustainable progress is to monitor water quantity

Received 4 March 2023; revised 10 June 2023; accepted 12 June 2023.
Available online 18 August 2023

* Corresponding author at: Ministry of water resources and irrigation, Elsalam City, Mansoura, Dakahlia 35111, Egypt.
E-mail address: bago@f-eng.tanta.edu.eg (M. ElBagoury).

https://doi.org/10.58491/2735-4202.3066

and quality while also controlling water resource pollution (Elhaddad and Al-Zyoud, 2017; Ibrahim et al., 2018). Different researchers have assessed the water quality of rivers, estuaries, reservoirs, and lakes by using many applications of Water Quality Index (WQI) models. The WQI model is a common tool for assessing the quality of surface water. It uses aggregation methods to reduce large amounts of data on water quality into an index or single value (Uddin et al., 2021). Different publications offer a full review of WQIs (Uddin et al., 2021; Sutadian et al., 2016). The WQI technique has been employed as a water quality assessment measure throughout the world (Dunca, 2018; Fathi et al., 2018; Khan et al., 2016; Massoud, 2012; Son et al., 2020; Wikurendra et al., 2022).

Using the Canadian Council of Ministries of the Environment-Water Quality Index (CCME-WQI), Reda and colleagues (Reda et al., 2015) assessed the drinking water stations on the Nile upstream of Cairo. The results showed significant concentrations of COD and fecal coliform (FC). Abdel-Satar and colleagues (Abdel-Satar et al., 2017) used CCME-WQI, metal pollution, and contamination indices to evaluate the water quality conditions of the Nile from Aswan to Cairo and investigate whether it was suitable for drinking and aquatic life uses. Furthermore, the WQI was used in 2018 to evaluate the water quality status of the Nile River at Cairo, and the WQI was excellent for irrigation uses, good for aquatic life uses, and poor for drinking uses (Al-Afify et al., 2018). Along the Damietta Branch in Egypt, there are a range of water quality conditions. The WQI was applied by Elhadad and colleagues (Elhadad et al., 2021) to evaluate the water quality of the Damietta branch for use in agriculture. They selected seven stations, and the results disclosed that the water quality index ranged from medium at some sites in the study area too bad at another site. El Sayed and colleagues (El Sayed et al., 2020) conducted a study to assess the water quality of the Nile branches, Rosetta and Damietta, using the CCME-WQI and two different biological indices. The water quality of the Damietta branch was ‘good’ for irrigation and aquatic life and ‘fair’ for drinking water; however, it is rated as ‘moderate’ based on the biological indices. Badr and colleagues (Badr et al., 2013a; Badr et al., 2013b) examined the condition of the water quality of the Damietta branch in governorates Damietta and Dakahlia by applying the WQI approach. According to the WQI, the concentrations of the major chemical components are ‘good’ in upstream Dakahlia Governorate but ‘relatively polluted’ in downstream Damietta Governorate. Researchers attribute this result to agricultural drains, domestic wastewater, industrial discharge, and human activities, all of which have an impact on the Nile in Damietta Governorate. El-Bady and Metwally (El-Bady and Metwally, 2016) applied the WQI for the Damietta branch; the authors reported that the water was ‘suitable’ for irrigation, while some of it was ‘unfit’ for drinking. The water in the southern part of the study area was generally acceptable for all uses. Hasaballah and colleagues (Hasaballah et al., 2019) used the WQI for the branch from Cairo to Ras-Elbar, Damietta, and the water quality conditions on Damietta branch were classified from medium to bad based on the WQI. Furthermore, they demonstrated that the estuary of the Damietta Branch experienced gradual ecological degradation.

The study intends to evaluate the Nile River's water quality at the Damietta Branch in Dakahlia Governorate by using the WQI to arrange enormous amounts of water quality data into concise and simple categories (e.g., excellent, good, average, or poor) to give a comprehensive state of the pollution in the research region.

3. Material and methods

3.1. Study area

The longest river in the world is the Nile, measuring approximately 6695 km overall and 1352 km within Egypt (Anonymous, 2016). Behind the Aswan High Dam, the Nile River flows for 940 km before splitting at the El-Qnater Barrage into two branches: the western branch, Rosette, and the eastern branch, Damietta Elewa (Elewa, 2010). Damietta Branch is located in the eastern region of the Nile Delta. It is about 241 km long, with an average depth of 11 m, an average width of 280 m, and an average elevation of 2 m Hasaballah and colleagues (Hasaballah et al., 2019). The Damietta Branch in the Nile Delta passes through the governorates of Damietta, El-Dakahlia, El-Gharbia, El-Menofyia, and El-Qaliubiah, where it is the only surface water source for activities related to domestic, agriculture, municipalities, and industries (Abdel-Dayem, 2011). Faraskour Dam, also known as Damietta Dam, divides the branch into two sections: freshwater upstream and saline water downstream. The amount of waste discharged to the Damietta Branch is increasing from several kinds of pollution sources, including agriculture and industry (APRP, 2002). The primary causes of pollution in the Damietta branch are the effluents of the

Talkha electric power station and the Talkha fertilizer industry, as well as the discharge of many minor agriculture drains and neighboring villages El Sayed and colleagues (El Sayed et al., 2020).

The study area extends for about 60 km along the Damietta Branch in the Dakahlia Governorate, Egypt. It is considered to be the major water supply for a large sector of the governorate through 11 intakes: Nawsa-Elbahr (St 1), Mit-Elkorama (St 2), Mit-Khamis (St 3), Talkha (St 4), Mansoura (St 5), Mit-Antar (St 6), Eltawila (St 7), Batra (St 8), Shirbin (St 9), Busat-Karimeldin (St 10), and Ras-Elkhalig (St 11), as can be seen in Fig. 1. Table 1 represents the station locations and names from different sources from which data was collected.

3.2. Data collection

Parameters of water quality were gathered over four consecutive years, from the first of 2018 to the end of 2021, for the 11 drinking water station intakes along the Damietta Branch in El-Dakahlia Governorate, from drinking water station Nawsa-Elbahr station (St 1) to drinking water station Ras-Elkhalig station (St 11), as shown in Fig. 1. 30 physical, chemical, and biological parameters shown in Table 2 were collected by the Central Laboratory of the Holding Company for Water and Wastewater, El-Dakahlia Governorate. The collected water quality parameters were measured daily or monthly for the period of the study. Boxplot representation graphs for

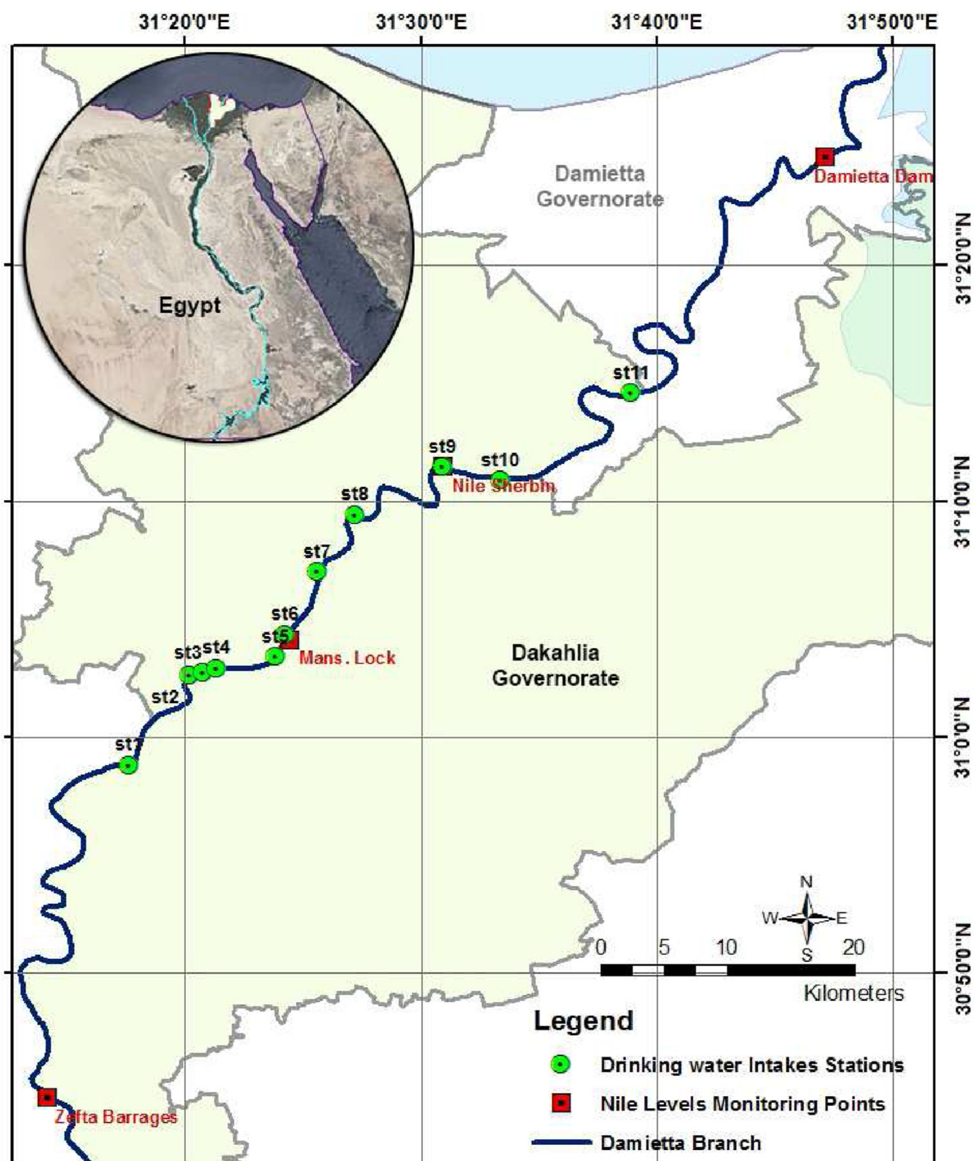


Fig. 1. The study area and Stations location in the Damietta branch, Nile, Egypt.

Table 1. Location and data collection sources of stations in the selected study area.

Code	HCWW[a]			EMD-MHP[b]	Location NDBNP-MWRI[c]			
	Stations Names	Station kind	Intake kind	Monitoring point	Bank	km	Latitude	Longitude
St 1	Nawsa-Elbahr	Compact St.	Extended	Nawsa-Elbahr	Right	135.56	30°58′48.33‘N	31°17'39.25‘E
St 2	Mit-Elkorama	Compact St.	Extended	Mit-Elkorama	Left	144.58	31° 2'36.02‘N	31°20'13.02‘E
St 3	Mit-Khamis	Main St.	Shore	Mit-Khamis	Right	145.52	31° 2'42.63‘N	31°20'47.57‘E
St 4	Talkha	Main St.	Extended	Talkha	Left	146.50	31° 2'54.60‘N	31°21'23.19‘E
St 5	Mansoura	Main St.	Extended	Mansoura	Right	150.16	31° 3'7.85‘N	31°23'39.93‘E
				Toril	Right	150.67	31° 3'22.62‘N	31°23'52.22‘E
St 6	Mit-Antar	Compact St.	Extended	Delta Fertilizers Co	Left	152.55	31° 4'19.29‘N	31°24'16.82‘E
St 7	Eltawila	Compact St.	Extended	Eltawila	Left	158.00	31° 6'58.44‘N	31°25'37.25‘E
St 8	Batra	Compact St.	Extended	Batra	Left	163.81	31° 9'24.07‘N	31°27'13.16‘E
St 9	Shirbin	Main St.	Shore	Shirbin	Left	175.31	31°11'25.93‘N	31°30'56.62‘E
St 10	Busat-Karimeldin	Main St.	Extended	Busat-Karimeldin	Right	179.27	31°10'51.19‘N	31°33'24.38‘E
St 11	Ras-Elkhalig	Compact St.	Extended	Ras-Elkhalig	Left	195.68	31°14'34.53‘N	31°38'58.19‘E

[a] **HCWW** is the Holding Company for Water and Wastewater.
[b] **EMD-MHP** is the Environmental Monitoring Department of the Preventive Medicine Department, the Ministry of Health and Population.
[c] **NDBNP-MWRI** is the North Damietta Branch Nile Protection, the Ministry of Water Resources and Irrigation.

Table 2. Summary of the available physical, biological, and chemical parameters of the selected study area in the Damietta Branch.

No					Tolerance Limits[a]			
	Parameters		Symbol	Unit	Article No. 49	Article No. 50	Article No. 51	Recommended limit
1	Physical Parameters	Temperature	T	C °	average + 3	average + 3	average + 3	average + 3
2		Turbidity	NTU	NTU			10	10
3		Electrical Conductivity	EC	µS/cm				
4		Total Dissolved Solids	TDS	mg/L	500	800	2000	500
5	Chemical Parameters	Hydrogen ion concentration	pH	Unit	6.5–8.5	6–9	6.5–8.5	6.5–8.5
6		Total Alkalinity	T.Alk	mg/L			200	200
7		Chloride	CL^-	mg/L				
8		Total Hardness	TH	mg/L				
9		Dissolved Oxygen	DO	mg/L	>6		>5	>6
10		Chemical Oxygen Demand	COD	mg/L	10	30	50	10
11		Biological oxygen demand	BOD	mg/L	6	20	30	6
12		Ammonia	NH_4^+	mg/L	0.5	1		0.5
13		Nitrate	NO_3^-	mg/L	2			2
14		Magnesium	Mg^{2+}	mg/L			50	50
15		Nitrogen Dioxide	NO_2^-	mg/L			0.9	0.9
16		Sulfate	SO_4^{2-}	mg/L	200			200
17		Calcium	Ca^{2+}	mg/L			75	75
18		Total phosphorus	TP	mg/L	2	1	3	1
19		sodium	Na^-	mg/L			200	200
20		potassium	K^+	mg/L			10	10
21	Biological Parameters	Total coliform	TC	CFU/100 ml			5000	5000
22		Algal count	Alg.C	Unit				
23		Blue Green Algae	BG.Alg	Unit				
24		Green Algae	G.Alg	Unit				
25		Diatoms	Diatoms	Unit				
26		Total Bacterial count	TBC	CFU/ml				
27		Fecal coliform	FC	CFU/100 ml				
28		Fecal strepto coccus	FSC	Unit/L				
29		Protozoa		Unit/L				
30		Worms		Unit/L				

[a] The Egyptian tolerance limits of law No. 48/1982 and its executive Regulations No. 8/1982, regarding the protection of the Nile River and waterways from pollution, and the ministerial resolutions No. 402/2009, 92/2013, and 208/2018, amending some provisions of the executive regulations, Chapter VI, Article No. 49, the limits of fresh water to which it is permitted to discharge treated liquid industrial waste; Article No. 50, the limits of the Nile River and its branches, to which it is permitted to drain treated liquid industrial wastewater; and Article No. 51, the limits of freshwater bodies to which agricultural drains are permitted to be drained (for agricultural purposes).

some selected parameters are chosen from twenty-one out of the 30 collected parameters. A dataset is generally presented as four values: extreme, minimum, maximum, and median. The Egyptian tolerance limits of Law 48/1982 and the amended Regulations 92/2013, have been applied.

3.3. Statistical analysis

The authors compared the data using one-way and two-way ANOVA and conducted correlation analysis of the different stations at the study area using IBM-SPSS for Windows to calculate the statistical analysis and draw box plot graphs for the parameters available for all stations.

3.4. Water quality index (WQI)

The WQI is a major element in the assessment and management of surface water. WQI is one of the best ways to express water quality and provides a simple, reliable unit of measurement Abd-Alwahed (Abd-Alwahed, 2015).

Water's suitability for various uses is assessed using the WQIs. The rankings of the water quality in rivers, streams, reservoirs, and lakes are shown by these indices. The concept of WQIs is the comparison of the water quality indicators with their corresponding regulatory standards Al-Bahrani and colleagues (Al-Bahrani et al., 2012).

There are several ways to quantify the water quality index. In this study, the Arithmetic Weighted Method (AW-WQI) and the Canadian Method (CCME-WQI) were selected.

3.4.1. Weighted arithmetic WQI (WA-WQI)

The method of Weighted Arithmetic mean used by Muntasir and colleagues (Muntasir et al., 2011) and Oboh and Egun (Oboh and Egun, 2017), to classify water quality by using the most widely measured water quality parameters according to pure degree. The WA-WQI was initially proposed by Horton (1965), and Brown (Brown, 1972) developed it. The following equation was utilized to calculate WQI:

$$Sub\ index = \sum_{i=1}^{i=n} Qi * WI \quad (1)$$

where, n is the number of determinants, Q_i is the quality rating scale, WI is the relative unit weight.

The quality rating scale (Qi) for each parameter can be calculated by using the equation:

$$Qi = 100 * \left[\frac{V_i - V_0}{S_i - V_0}\right] \quad (2)$$

where, V_i is the observed parameter Concentration, V_0 is the ideal value of the parameter in pure water, $V_0 = 0$ (except pH = 7.0 and DO = 14.6 mg/l), and S_i is Recommended Standard value (permissible Limit).

Unit weight (Wi) for each parameter of the water quality can be calculated by using the following formula:

$$WI = \frac{wi}{\sum wi} \quad (3)$$

where, w_i is the weighted factor.

According to Fig. 2, the WA-WQI ranks are divided into five categories. In this study, all possible parameters are limited by the Egyptian permissible limits of the Law No. 48/1982, and the amended Regulations 92/2013.

3.4.2. The Canadian Council of Ministries of the environment WQI (CCME-WQI)

The Canadian Council of Ministers of the Environment created the CCME-WQI as a tool for reporting and assessing the data on water quality to the public and management institutions Abdul-Rahman and colleagues (Abdul-Rahman & A-hmad, 2013). The CCME-WQI can be calculated by the following equation:

$$CWQI = 100 - \left(\frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732}\right) \quad (1)$$

where, 1.732 is the correction factor, F_1, F_2, and F_3 are factors defined as scope, frequency, and amplitude, respectively. F_1 (Scope) is the percentage of a variable that surpasses the permissible value. F_2 (Frequency) exemplifies the proportion of individual tests that fail to achieve objectives (failed tests). F_3 (Amplitude) is the amount by which failed test values do not meet their targets. These factors can be calculated as follows:

$$F_1(Scope) = \left[\frac{Faild\ of\ number\ parameters}{Total\ number\ parameters}\right] \times 100 \quad (2)$$

$$F_2(Frequency) = \left[\frac{number\ of\ Faild\ tests}{Total\ number\ tests}\right] \times 100 \quad (3)$$

$$F_3(Amplitude) = \left[\frac{nse}{0.01\ nse + 0.01}\right] \times 100 \quad (4)$$

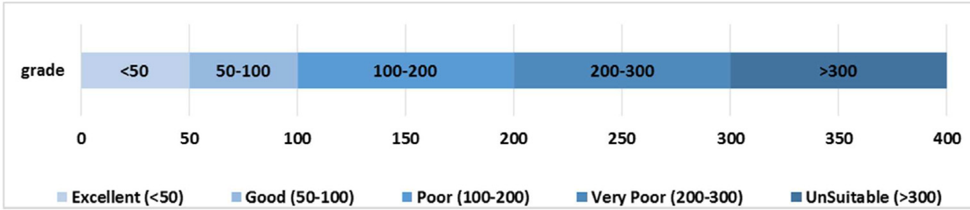


Fig. 2. Classification of water quality under WA-WQI.

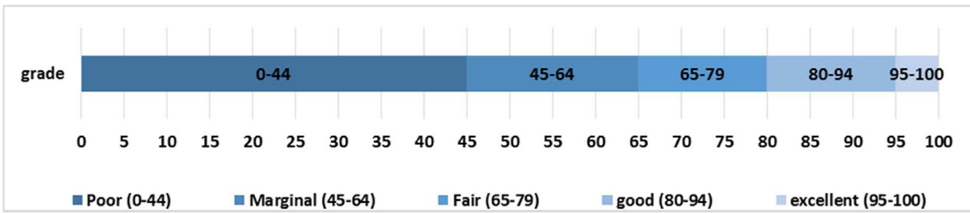


Fig. 3. Classification of water quality under CCME-WQI.

The index comprises three factors: F_1, F_2, and F_3. The combination of these three factors gives a single value between 0 and 100 that interprets the water quality. The ranks of CCME-WQI are classified into five categories, as shown in Fig. 3. Available parameters are limited by the standards of Egyptian law and its ministerial regulations.

4. Results and discussions

4.1. Statistical analysis results

The physical, biological, and chemical analyses of water quality samples at stations are indicated in Fig. 4. Results showed that all the considered parameters were within the allowable tolerance limits of Egyptian Law 'protecting the Nile River from pollution' No. 48/1982, and its ministerial decree No. 92/2013 for surface water, except the maximum values of the four years (2018–2021) for Turbidity, Chloride, COD, BOD, Ammonia, and Total Coliform. And maximum values of Total Alkalinity, Nitrogen Dioxide, Calcium, Total Phosphorus, and Potassium for the years (2020, 2021, 2018, 2018, and 2021), respectively.

4.1.1. Correlation matrix between parameters

Statistical analysis for significant correlations (at the 95%–99% level) between two parameters of water quality was calculated by a correlation matrix (Pearson's product moment) using IBM-SPSS for Windows in order to give guidance in the explanation of the data (Table 3). Positive, significant correlations indicate proportional relationships between two water quality parameters. However, significant negative correlations indicate an inverse relationship between the observed parameters Badr and colleagues (Badr et al., 2013a; Badr et al., 2013b).

Table 3 represents the correlations between the available parameters for the Damietta branch. The authors found the following significant correlation:

First, a significant positive correlation (99% confidence) was found between EC, TDS, T.Alk, CL^-, TH, DO, SO_4^{2-}, and Na^-. And between BOD and COD. The correlation between TDS and DO supports the fact of inversely proportional between the concentrations of dissolved oxygen and the salinity. And between pH, T.Alk, and TC. Also, between T.Alk, CL^-, TH, DO, SO_4^{2-}, Na^-, and NH_4^+. And between Fe^{2+} and K^+.

The strong positive correlation between BOD and COD can be represented in Fig. 5, as well as between TH and TDS values, as shown in Fig. 6, which revealed a positively strong correlation to each other.

Second, there was a positive significant correlation (95% confidence) between Fe^{2+}, EC, TDS, T.Alk, CL^-, TH, DO, SO_4^{2-}, Na^-, and TC.

Third, there was a high negative correlation (99% confidence) between temperature, EC, TDS, T.Alk, CL^-, TH, DO, SO_4^{2-}, Na, and Fe^{2+}.

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are closely related; the distinction between COD and BOD is that BOD indicate to the quantity of organic matter that can

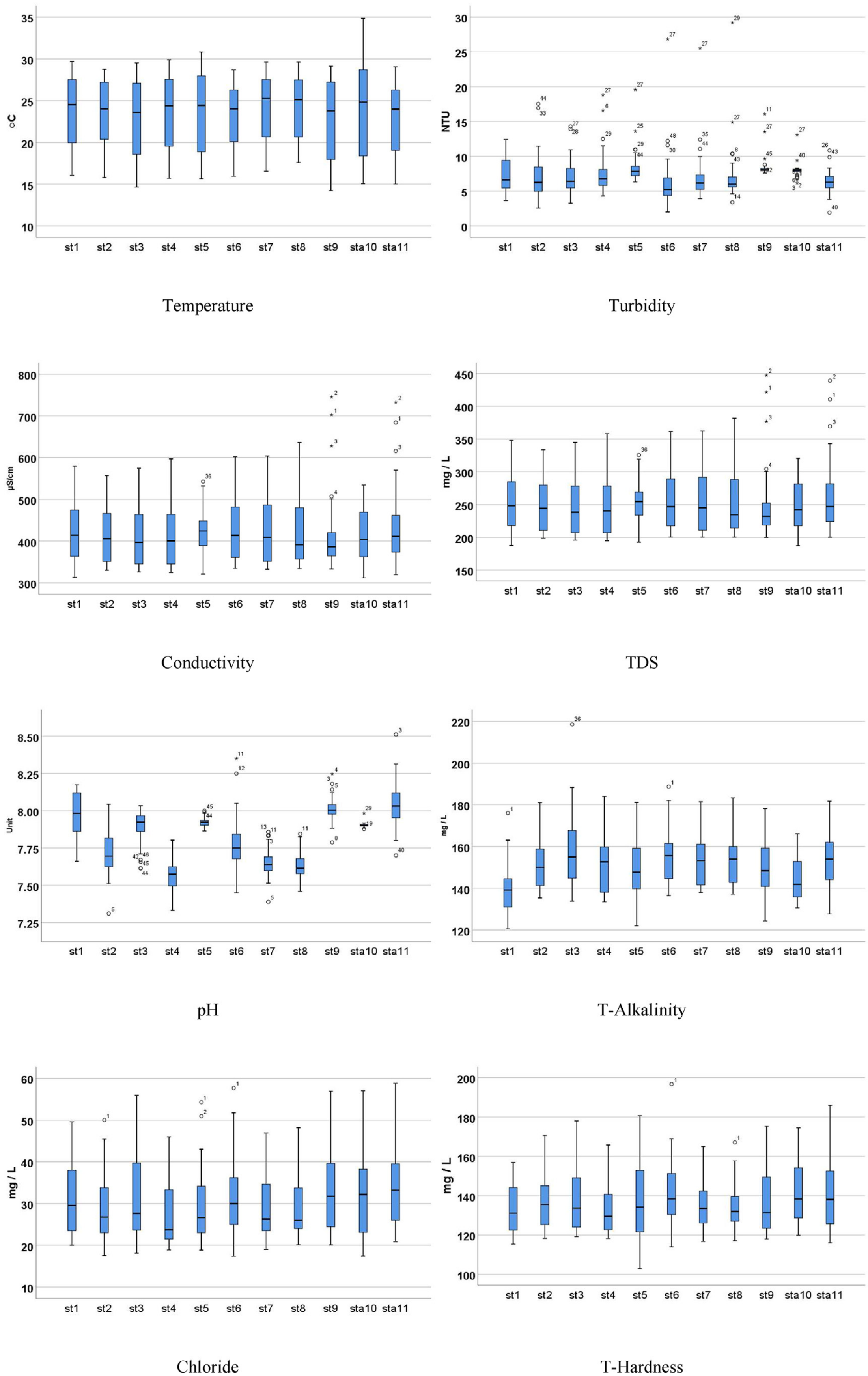
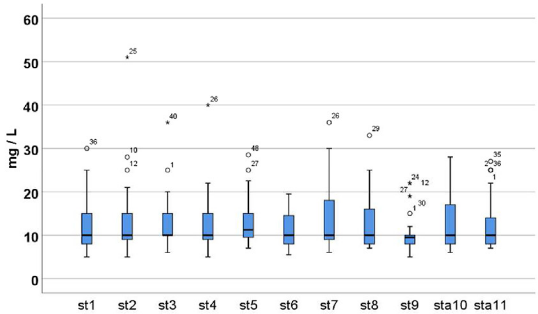
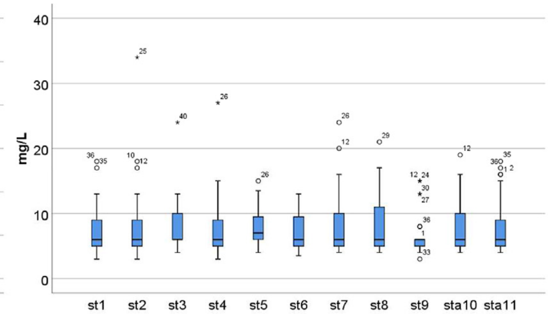


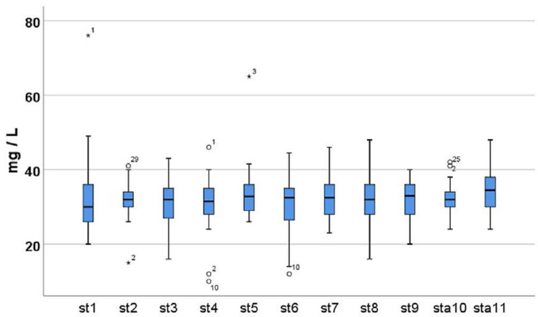
Fig. 4 A boxplot for the study area stations located in the Damietta branch, Nile, Egypt.



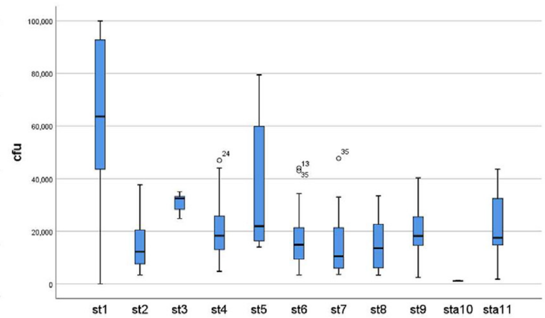
COD



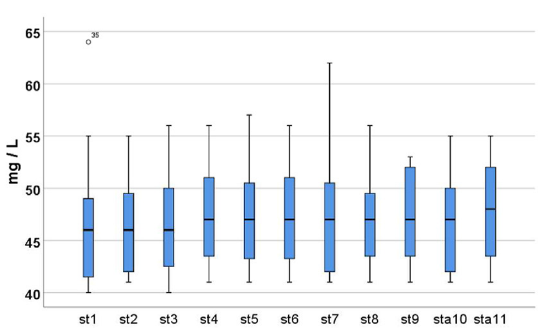
BOD



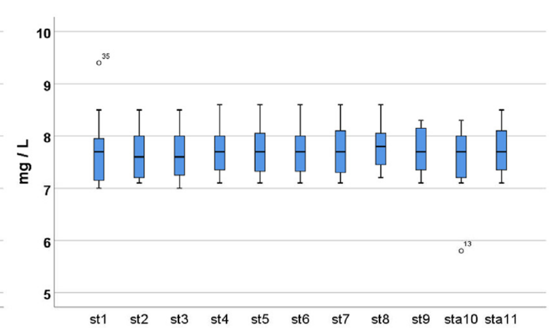
Ca^{2+}



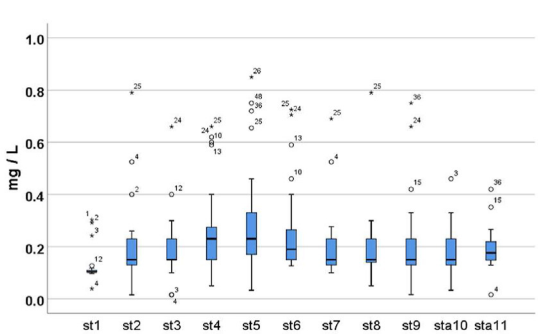
Total Coliform



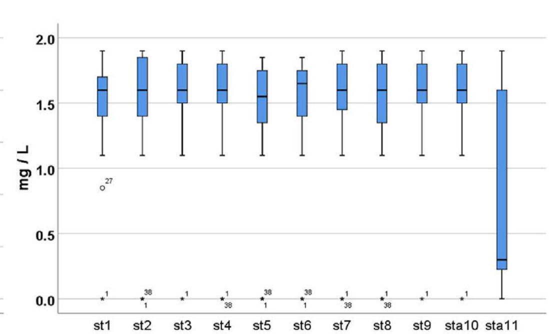
Na^{+}



K^{+}



NH_4^{+}



NO_3^{-}

Fig. 4 (Continued)

Table 3. Correlation matrix between parameters for the Damietta branch.

	T	NTU	EC	TDS	pH	T.Alk	Cl	TH	DO	COD	BOD	NO2	SO4	Ca	TP	Na	K	NH3	NO3	Iron	Mn	T.C
T	1																					
NTU	0.096	1																				
EC	−0.836[a]	−0.18	1																			
TDS	−0.836[a]	−0.18	1.000[a]	1																		
pH	−0.468[a]	−0.288[b]	0.502[a]	0.503[a]	1																	
T.Alk	−0.731[a]	−0.245[b]	0.882[a]	0.883[a]	0.676[a]	1																
Cl	−0.887[a]	−0.18	0.965[a]	0.965[a]	0.510[a]	0.863[a]	1															
TH	−0.878[a]	−0.19	0.979[a]	0.979[a]	0.521[a]	0.896[a]	0.971[a]	1														
DO	−0.871[a]	−0.498[a]	0.640[a]	0.641[a]	0.548[a]	0.621[a]	0.745[a]	0.714[a]	1													
COD	−0.278[b]	−0.15	0.379[a]	0.379[a]	0.194	0.328[b]	0.334[b]	0.395[a]	0.18	1												
BOD	−0.270[b]	−0.15	0.355[a]	0.355[a]	0.16	0.294[b]	0.311[b]	0.380[a]	0.175	0.993[a]	1											
NO2	−0.18	−0.03	0.081	0.081	0.046	−0.06	0.15	0.089	0.05	−0.16	−0.17	1										
SO4	−0.631[a]	−0.12	0.716[a]	0.716[a]	0.491[a]	0.685[a]	0.759[a]	0.759[a]	0.713[a]	0.307[b]	0.373[a]	0.09	1									
Ca	−0.425[a]	0.232	0.341[a]	0.341[a]	0.139	0.222	0.367[a]	0.352[a]	0.267	−0.06	−0.06	0.039	0.287[b]	1								
TP	0.012	−0.242[b]	0.221	0.221	0.394[a]	0.359[a]	0.176	0.214	−0.03	0.296[b]	0.254[b]	−0.13	0.097	−0.02	1							
Na	−0.881[a]	−0.19	0.947[a]	0.947[a]	0.494[a]	0.912[a]	0.970[a]	0.969[a]	0.737[a]	0.385[a]	0.406[a]	.c	0.756[a]	0.268[b]	0.136	1						
K	−0.17	−0.12	0.331[b]	0.331[b]	0.06	0.265[b]	0.276[b]	0.295[b]	0.011	0.178	0.198	.c	0.260[b]	−0.379[a]	−0.03	0.318[b]	1					
NH3	−0.410[a]	−0.350[a]	0.549[a]	0.550[a]	0.348[a]	0.653[a]	0.528[a]	0.574[a]	0.382[b]	0.226	0.226	−0.12	0.347[a]	0.041	0.292[b]	0.576[a]	0.225	1				
NO3	0.137	0.168	−0.2	−0.2	−0.05	−0.16	−0.22	−0.22	0.055	−0.06	−0.06	−0.353[a]	−0.371[a]	−0.04	0.056	0.013	−0.23	−0.12	1			
Iron	−0.966[a]	−0.41	0.854[b]	0.854[b]	0.959[a]	0.924[b]	0.921[b]	0.912[b]	0.844[b]	−0.03	−0.01	.c	0.932[b]	0.556	0.258	0.932[b]	0.947[a]	0.432	−0.34	1		
Mn	−0.316[b]	−0.327[b]	0.486[a]	0.485[a]	0.267[b]	0.355[a]	0.444[a]	0.421[a]	0.21	0.244[b]	0.196	−0.03	0.270[b]	−0.261[b]	0.146	0.382[a]	0.405[a]	0.278[b]	−0.08	0.693	1	
T.C	−0.05	−0.289[b]	0.111	0.112	0.616[a]	0.469[a]	0.092	0.131	0.27	0.067	0.039	−0.251[b]	0.18	−0.245[b]	0.345[a]	0.251	0.101	0.225	0.198	0.853[b]	0.088	1

[a] Correlation is significant at the 0.01 level (1-tailed).
[b] Correlation is significant at the 0.05 level (1-tailed).

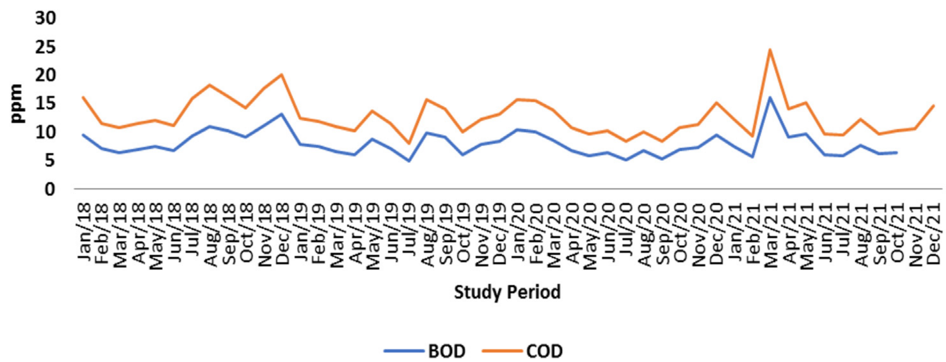


Fig. 5. Correlation between BOD and COD for Damietta branch, Nile, Egypt.

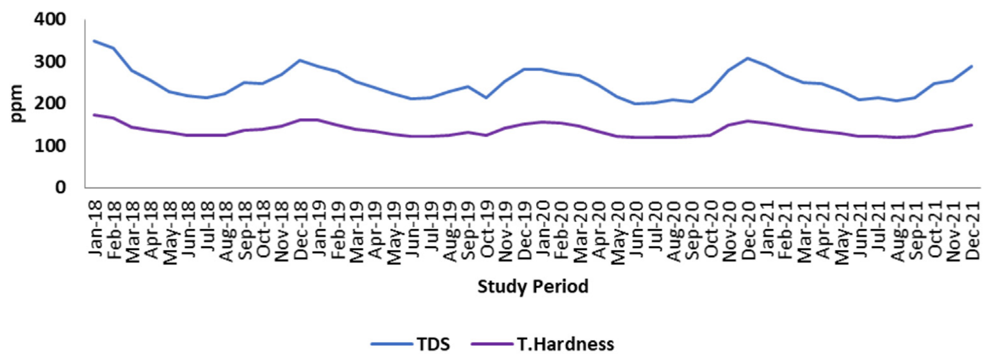


Fig. 6. Correlation between TDS, and TH for Damietta branch, Nile, Egypt.

be biologically oxidized, while COD indicate to the quantity of organic matter that can be chemically oxidized. The concentration of both assimilable and non-assimilable organic components is expressed by COD, whereas BOD exclusively indicates the concentration of assimilable organic materials. This explains why COD is usually greater if compared with BOD, as shown in Fig. 5; this conclusion was found to be in good agreement with Zaher and Hammam (Zaher and Hammam, 2014).

Hardness refers to the measurement of magnesium and calcium ions present in freshwater, whereas TDS refers to total dissolved solids, which comprise organic and inorganic substances. Total hardness will always be less than or equal to TDS when expressed in the same units (as CaCO3); this can be seen in Fig. 6, since hardness salts contribute to the total dissolved solids. They are related, but not really directly. If hardness goes up, so does TDS for water, but the opposite does not

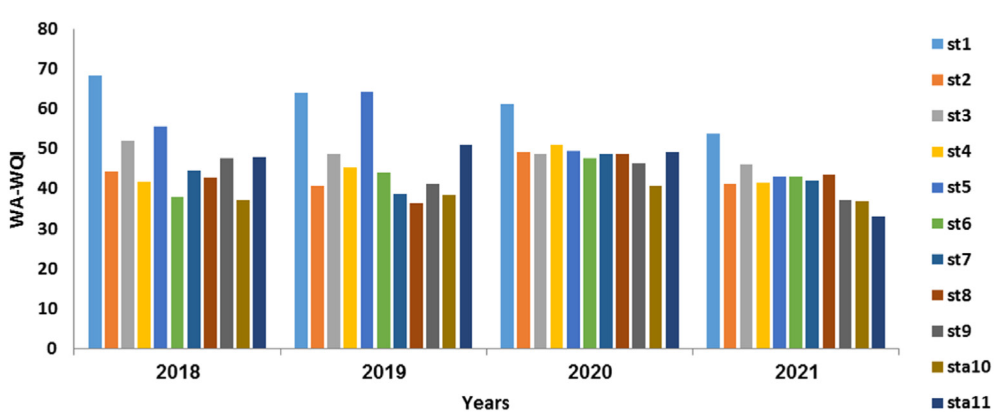


Fig. 7. WA-WQI for the stations located in the Damietta branch, Nile, Egypt.

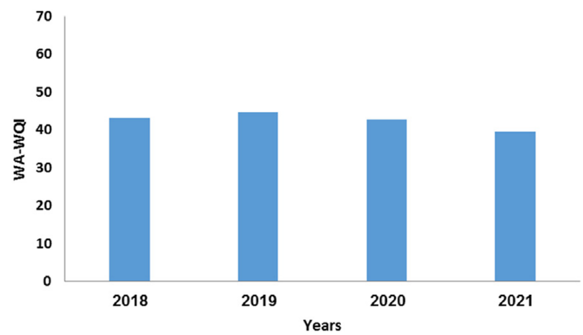


Fig. 8. Annual average WA-WQI for the Damietta branch, Nile, Egypt.

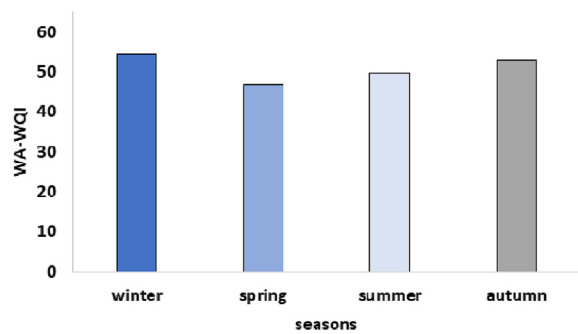


Fig. 9. Seasonal average WA-WQI during the study period for the Damietta branch, Nile, Egypt.

necessarily have to be true. You could have a high TDS and no hardness. This outcome was in good agreement with Xiao and colleagues (Xiao et al., 2021).

4.2. WQI results

The water quality index (WQI) was calculated using two approaches for the study area.

Physical and chemical parameters at eleven station locations along the Damietta branch of the Nile

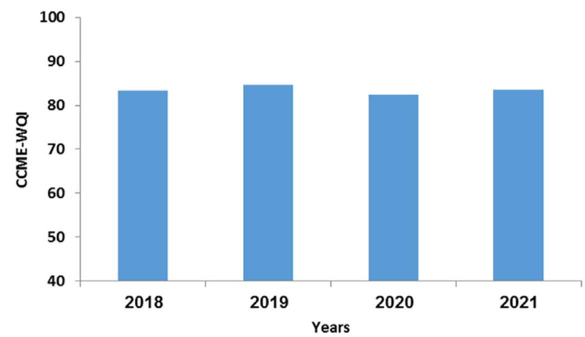


Fig. 11. Annual average CCME-WQI for the Damietta branch, Nile, Egypt.

River were analyzed to determine the WQI. These parameters were *Temperature, Turbidity, Electrical Conductivity, Total dissolved solids, pH, Total Alkalinity, Chloride, Total Hardness, Dissolved Oxygen, Chemical Oxygen Demand, Biological Oxygen Demand, Nitrogen, Sulfate, Calcium, Total phosphorus, Sodium, Potassium, Nitrate, Magnesium, and Total Coliform*.

Physical, chemical, and biological characteristics of water samples were measured and collected by the Holding Company for Water and Wastewater (HCWW) and the Environmental Monitoring Department of the Preventive Medicine Department, Ministry of Health and Population (EMD-MHP) along the study area at Damietta Branch, Nile River, to assess the quality. The results reveal that, with some exceptions, the overall mean values of parameters for all stations were within the limit allowed by the EOS for surface water. Relatively higher turbidity, BOD, COD, ammonium, potassium, total phosphorus, and total coliform concentrations are reported for collected water samples.

During the period of this study, the values of temperature varied from 14.22 to 34.85 C, turbidity

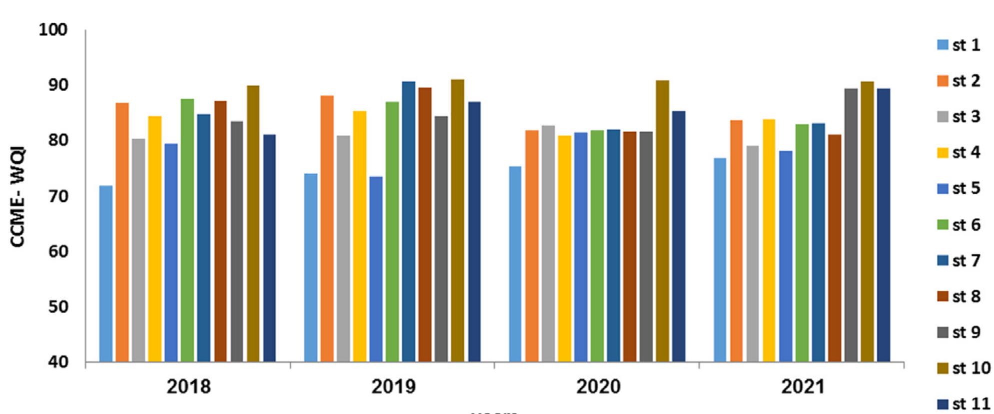


Fig. 10. CCME-WQI for the stations located in the Damietta branch, Nile, Egypt.

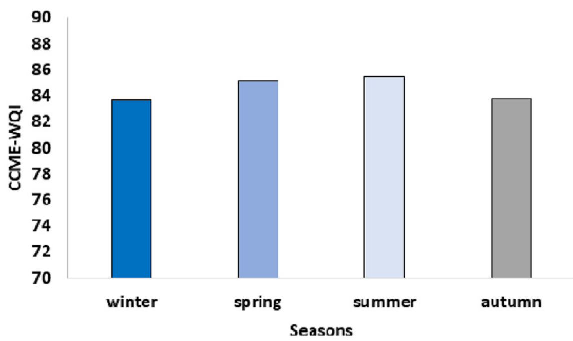


Fig. 12. Seasonal average CCME-WQI during the study period for the Damietta branch, Nile, Egypt.

ranged from 1.9 to 29.21 NTU, and EC was 312.16–745.54 μmho/cm, while TDS values were 187.3–447.32 ppm, pH limited was 7.31–8.51, and the total alkalinity was between 120.53 and 218.53 ppm, total hardness was between 102.81 and 196.67 ppm. The values of BOD and COD were 3–34 and 5 to 51, respectively, and the concentrations of Ca^{+2}, Mg^{+2}, Na^{-}, K^{+} were between 9 and 76 ppm, 2 and 41 ppm, 40–64 ppm, and 5.8–45 ppm, respectively. The chloride concentration was from 17.33 to 58.8 ppm and sulfate from 6.3 to 93 ppm. The concentration of total phosphorus was (0.01–1.2), ammonium was 0.02–2.00, and total coliform was 0–54 000.

For all studied stations, weighted arithmetic and Canadian methodologies were used to calculate the WQIs overall mean, which are graphically represented in Figs. 7–12.

4.2.1. The weighted arithmetic index (WA-WQI)

Damietta branch, Nile River, lies within the range of 0–50 of the WA-WQI classification scale as shown in Figs. 7–9, which indicates good suitability

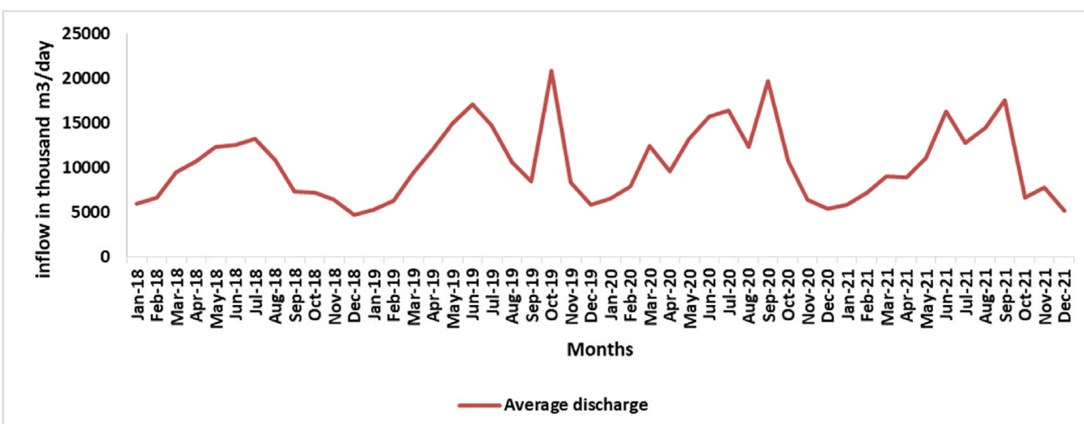


Fig. 13. Monthly average discharge of downstream Zifta barrage.

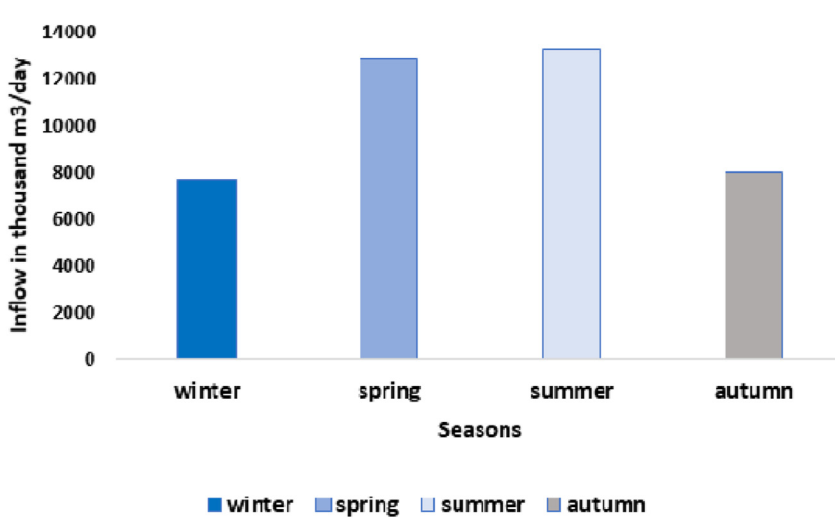


Fig. 14. Seasonal average discharge of downstream Zifta barrage during the study period.

for surface water uses according to the tolerance limits of Egyptian Law No. 48/1982 and its executive regulations.

4.2.2. The Canadian Council of Ministries of the environment index (CCME-WQI)

CCME-WQI indicates that the Damietta branch of the Nile River indicates good and excellent suitability for surface water use according to the tolerance limits of Egyptian Law No. 48/1982 and its executive regulations, as represented in Figs. 10–12.

The water quality results are somehow similar in both WQI methods, WA-WQI and CCME-WQI, for the Damietta branch and are good. There is a slight difference between the water quality of the selected stations, as shown in Figs. 7 and 10, and this may be due to the different types of stations, as stations No. 3, 4, 5, 9, and 10 are classified as main stations that draw large amounts of surface water, while the rest of the stations are compact stations that draw relatively less water. Or this may be due to the difference in the types of spatial intakes in terms of coastal or extended, as stations 3 and 9 have coastal intakes on the Nile bank and the rest of the stations have extended intakes, noting that the coastal intakes have a lower flow velocity due to their nearness to the rough surface of the side slopes of the river. This area is highly exposed to some deposition, which is usually near the bank slopes, and algae are more likely to appear in those areas than others.

The water quality results of stations No. 1, 3, 5, 9, and 11 are lower than others due to an increase in the total coliform parameter in them during the four years, as shown in Fig. 4, except stations No. 9 and 11 in 2021, which started to decline a little.

The relative deterioration of water quality at station 1 may be due to the fact that it is the nearest station to the main agricultural drainage Omar-Bik, which discharges directly on the Nile, and they are separated by about 8 km upstream of the station. Also, Mansoura river bus quays are quite near upstream stations No. 5 and 6, and it may cause a little deterioration in water quality for this station because of human and navigation activities. It is worth noting that the river bus in Mansoura started construction in September 2018 and started operating in July 2019. This may explain the reason for the lack of water quality, which has decreased since August 2019 at these stations.

4.3. Water quality and water quantity

Water quantity discharged in the Damietta branch is considered a major control in the results of water quality, noting that a large amount of water reduces pollution by dilution and increases water quality, and vice versa. This supports the fact that water quantity and quality can mutually reinforce each other and that water quality is affected by water quantity.

The Water Resources and Irrigation Ministry observes the Water discharge and levels in real-time for entire watercourses; this data is recorded daily. The monthly average inflow in m^3/day has been calculated in Fig. 13. Also, the seasonal average was calculated in m^3/day during the study period, as shown in Fig. 14.

WQI was applied to the four seasons for the study period in both methods. It was found that during the winter and autumn, the quality was lower than during the summer and spring seasons, as shown in Figs. 9 and 12. This may be due to the change in the inflow discharged into branch ‘Damietta‘ of the Nile River through the Zifta barrages, as shown in Fig. 14, which are the main barrages that control the amount of water in this branch. Less water is discharged during the winter and autumn seasons, as shown in Fig. 13, because the kinds of crops grown during these seasons do not consume large quantities of water. Also, the annual winter closure starts from January 15 to February 1. It is worth mentioning that the Ministry of Water Resources and Irrigation conducts the annual winter closure, which involves holding the water from waterways for 15 days in order to maintain irrigation and drainage networks. This procedure begins in January of each year.

As for the spring and summer, they are the main seasons in which the rice crop is grown, and it is classified as a water-intensive crop that needs large amounts of water for irrigation, which makes the Ministry of Water Resources and Irrigation compelled to supply a large amount of water to meet the agriculture demand for the crop's needs in that period. It is worth mentioning that traditional rice and dry rice are planted in the period from mid-April to mid-May at the latest, i.e., planting cannot be delayed beyond mid-May, so that the crop does not lose its productivity. The rice season continues until it is harvested in mid-August of each year.

5. Conclusion

The water quality indices used for 4 years (from 2018 to 2021) show that the water quality ranges from fair to excellent for surface water uses at the drinking water intakes located in the Damietta branch of the Nile River, Egypt.

The results show that the water quality of the Nile upstream in the Dakahlia Governorate is generally better. While the Nile in the Dakahlia Governorate downstream is impacted by several causes of pollution, including the disposal of industrial and agricultural waste, In addition, the MWRI works on clearing the waterway of purification and dredging, and the not favored habits and human activities of the population. Hence, the Nile River downstream in Dakahlia Governorate is exposed to pollution stress, especially biological pollution, from several anthropogenic activities. Generally considered light pollution.

The natural ability of the ecosystem can break down waste in a certain amount, and to maintain this ability, the flow of waste into surface waters must be significantly restricted, by developing all the agricultural, and industrial processes that flow waste into the Nile, replacing the cultivation of common crops with other kinds that have efficient water use to start reducing consumption, and minimizing the amount of sewage waste.

To apply the principle of sustainable development, there must be upgrades in water quality management in Egypt by shifting from environmental monitoring and control measures towards pollution prevention management.

Authors contribution statement

The author, Mohamed ELBagoury, collected the water quality data, made the statistical analysis and water quality assessment, and wrote the manuscript.

The Supervision team consists of Dr. Hewida Omara and Dr. Bakenaz Zeidan. They made a great effort to produce this work, help doing the water quality assessment, and review the article.

Conflict of Interest

None declared.

References

Abd-Alwahed, R.A., 2015. Assessment of Water Quality for Al-Kufa River Using GIS.

Abdel-Satar, A.M., Ali, M.H., Goher, M.E., 2017. Indices of water quality and metal pollution of Nile River, Egypt. Egypt J Aquat Res 43, 21–29. https://doi.org/10.1016/j.ejar.2016.12.006.

Abdul-Rahman, E., A-hmad, M.F.A.-D., 2013. Comparison of water quality index at intakes of water treatment plants in Baghdad city. Tikrit J Eng Sci 20, 23–34.

Al-Afify, A.D.G., Othman, A.A., Ramadan, M.F., 2018. Characterization of chemical and microbiological quality of Nile River surface water at Cairo (Egypt). Rendiconti Lincei 29, 725–736.

Al-Bahrani, H.S., Razzaq, K.A.A., Saleh, S.A.H., 2012. Remote sensing of water quality index for irrigation usability of the Euphrates River. WIT Trans. Ecol. Environ. 164, 55–66.

APRP, 2002. Environmental Policy and Institutional Strengthening Indefinite Quantity Contract APRP — Water Policy Activity Contract PCE-I-00-96-00002-00 Task Order 22 SURVEY of NILE SYSTEM, p. 64.

Badr, E.-S.A., El-Sonbati, M.A., Nassef, H.M., 2013a. Water quality assessment in the Nile River, damietta branch, Egypt. In: CATRINA, 8. Issue 1.

Badr, E.-S.A., El-Sonbati, M.A., Nassef, H.M., 2013b. Water quality assessment in the Nile River , damietta branch , Egypt. Catrina. Int. J. Environ. Sci. 8, 41–50.

Brown, R.M., 1972. In: Thomas, W.A. (Ed.), Indicators of Environmental Quality. Springer. https://www.ptonline.com/articles/how-to-get-better-mfi-results.

Dunca, A.M., 2018. Water pollution and water quality assessment of major transboundary rivers from Banat (Romania). J. Chem. 2018, 1–8.

EEAA, 2008. Egyptian Environmental Affairs Agency. Egypt State of the Environment Report 2007, pp. 94–2007.

El Sayed, S.M., Hegab, M.H., Mola, H.R.A., Ahmed, N.M., Goher, M.E., 2020. An integrated water quality assessment of Damietta and Rosetta branches (Nile River, Egypt) using chemical and biological indices. Environ. Monit. Assess. 192, 228.

El-Bady, M.S.M., Metwally, H.I., 2016. Evaluation of water quality of the surface water of the damietta nile branch, damietta governorate, Egypt. Int. J. ChemTech Res. 9, 119–134.

Elewa, H.H., 2010. Potentialities of Water Resources Pollution of the Nile River Delta , Egypt, 1–13.

Elhadad, E., Ibrahim, M., Al-Fawwaz, A., 2021. Effects of pollution on hydrogeochemistry and water quality of the Damietta branch (Nile River, Egypt). Water Sci. Technol. 84, 1509–1517.

Elhaddad, E., Al-Zyoud, S., 2017. The quality assessment of pollution of Rosetta branch, Nile River, Egypt. Arabian J. Geosci. 10, 97.

Fathi, E., Zamani-Ahmadmahmoodi, R., Zare-Bidaki, R., 2018. Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. Appl. Water Sci. 8, 210.

Hasaballah, A.F., Hegazy, T.A., Ibrahim, M.S., El-Emam, D.A., 2019. Assessment of water and sediment quality of the river nile. Damietta Branch, Egypt 23 (Issue 5).

Ibrahim, M., Al-Zyoud, S., Elhaddad, E., 2018. Surface water quality monitoring for river nile, Egypt using GIS-techniques. Open J. Geol. 8, 161–173.

Khan, M.Y.A., Gani, K.M., Chakrapani, G.J., 2016. Assessment of surface water quality and its spatial variation. A case study of Ramganga River, Ganga Basin, India. Arabian J. Geosci. 9, 1–9.

Massoud, M.A., 2012. Assessment of water quality along a recreational section of the Damour River in Lebanon using the water quality index. Environ. Monit. Assess. 184, 4151–4160.

Muntasir, S.Y., Chowdhury, R.M., Musabbir, S.R., 2011. DHAKA. MAWA-BHANGA ROAD.

Nile Basin Initiative, Water Resources Atlas, 2016 (Online newsletter published monthly, presented at the NBI website. Available:).

Oboh, I.P., Egun, N.K., 2017. Utilization of water quality index (WQI) in water quality assessment of groundwater in Agbor metropolis, Delta state Nigeria. Int Sci Technol J Namibia Oboh & Egun 10 (July 2020), 48–55.

Reda, A., Riad, P., El-Gammal, H., Abd El-Razik, M., Nour El-Een, M., Khalifa, A., 2015. Water quality management information system upstream Cairo drinking water plants. Danish J. Eng. Appl. Sci. 14–29.

Son, C.T., Giang, N.T.H., Thao, T.P., Nui, N.H., Lam, N.T., Cong, V.H., 2020. Assessment of Cau River water quality assessment using a combination of water quality and pollution indices. J. Water Supply Res. Technol. - Aqua 69, 160—172.

Sutadian, A.D., Muttil, N., Yilmaz, A.G., Perera, B.J.C., 2016. Development of river water quality indices—a review. Environ. Monit. Assess. 188, 1—29.

Uddin, M.G., Nash, S., Olbert, A.I., 2021. A review of water quality index models and their use for assessing surface water quality. Ecol. Indicat. 122, 107218.

Wikurendra, E.A., Syafiuddin, A., Nurika, G., Elisanti, A.D., 2022. Water quality analysis of pucang river, sidoarjo regency to control water pollution. Environ. Qual. Manag. 32, 1—12.

Xiao, Y., Liu, K., Hao, Q., Li, J., Zhang, Y., Cui, W., Pei, Q., 2021. Hydrogeochemical Features and Genesis of Confined Groundwater and Health Perspectives for Sustainable Development in Urban Hengshui, North China Plain, vol. 2021.

Zaher, K., Hammam, G., 2014. Correlation between biochemical oxygen demand and chemical oxygen demand for various wastewater treatment plants in Egypt to obtain the Biodegradability indices. Int. J. Sci. Basic Appl. Res. 13, 42—48.